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# SELECTING THE BEST WAREHOUSE DATA COLLECTING SYSTEM BY USING AHP AND FAHP METHODS

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Original scientific paper
Recently companies have begun to use their storage effectively to attain leadership in the market environment, utilizing Barcode and RFID (Radio Frequency Identification) systems for warehouse management. In this study AHP (Analytic Hierarchy Process) and FAHP (Fuzzy Analytic Hierarchy Process) are used to choose between Barcode and RFID systems for the company warehouse data collection system. This decision is affected by four criteria which are: cost, functionality, sustainability and performance. The barcode system was preferred by 68 % and RFID was preferred by 32 % according to AHP. For FAHP, barcode system was preferred by 72 % and RFID was preferred by 28 %. Consequently AHP values are consistent with FAHP values. Finally barcode system is selected for the company's warehouse data collection system and FAHP is found to be relatively more sufficient in terms of description of this decision-making process because of its fuzziness and vagueness compared to AHP method.

***Keywords:*** *AHP, Automation Systems, Barcode, Fuzzy AHP, RFID*

## Izbor najboljeg sustava za dobivanje podataka o skladištu primjenom metoda AHP i FAHP

Izvorni znanstveni članak
U zadnje su se vrijeme kompanije počele koristiti načinom skladištenja kako bi stekle prednost na tržištu, uporabom sustava linijskog koda i RFID (Radio Frekvencijska Identifikacija) u vođenju skladišta. U ovom se radu koriste AHP (Analytic Hierarchy Process) i FAHP (Fuzzy Analytic Hierarchy Process) pri izboru sustava linijskog koda ili RFID sustava za sustav koji će kompanija odabrati kao način skladištenja. Na donošenje odluke djeluju četiri kriterija: cijena, funkcionalnost, održivost i performansa. U odnosu na AHP, sustav linijskog koda preferira 68 %, a RFID 32 %. Kad se radi o FAHPu linijski kod preferira 72 %, a RFID 28 %. Prema tome, AHP vrijednosti se slažu s FAHP vrijednostima. Konačno, sustav linijskog koda je odabran kao sustav za vođenje podataka o skladištu, a smatra se da je FAHP relativno uspješniji kad se radi o opisu tog postupka donošenja odluke zbog njegove nejasnoće (fuzziness) i neodređenosti u odnosu na AHP metodu.

***Ključne riječi:*** *AHP, sustavi automatizacije, linijski kod, Fuzzy AHP, RFID*

## 1 Introduction

A warehouse system is a critical component of an effective overall supply chain management system solution. In the international markets, logistics and stock activities, which are main parts of the supply chain, have become more vital along with the consistently changing market conditions. While previously the term "warehouse" was only perceived as a material stocking place, lately it is referring to a competition factor in the markets. The firms anticipating leadership in their sectors have started making improvements in their warehouse systems. These improvements enhance profits by eliminating difficulties in stock counting, decreasing the number of warehouse personnel and excess stocks. At the heart of these improvements, lie the shelves redesign and coding system improvements.

Prominent firms in their sectors generally have a diverse product range and warehouse facilities containing their products. Frequently, problems occur in the product sequence and firms handle these problems by the help of automation system solutions. An automation system is essentially a computer aided system which controls the movements of goods in a warehouse. While firms without warehouse automation systems suffer from operation expenses, poor customer satisfaction and efficiency, using automation systems provides increases in the amount of products that can be stored, saves time and decreases occupational health risks. Additionally, automation systems are mainly used in automotive, medical and food industries which require profound logistic information databases, strong supply chains and information systems. The two main systems which provide these industries with a stronger logistic structure are the Barcode and RFID.

Barcoding and RFID have emerged from the same roots, Auto Identification which is a broad category of technologies that are used to identify objects, humans and animals [1].

A Barcode which consists of lines in different thicknesses is a means to transfer data digitally in an easy and rapid way. Barcodes can help to ensure that the incoming product is put in the right place and that the outgoing product is picked in right quantities. By using barcode picking, not only can you pick faster, but you can also pick with virtually 100 % accuracy. The barcode system which gives information about product amount in stock in the warehouse is a widespread, easy and cheap product identification system. Besides, its defect rate is lower than other technologies.

RFID (Radio Frequency Identification) is a method used for identifying objects and living things. RFID enables real-time monitoring of inventory of goods using active RFID technology. It improves resource utilization by optimizing warehousing space and quantity of goods. It also improves the efficiency of logistics in terms of shipping, receiving, and storage and retrieval operations to eliminate operational disruptions. It evolves just in-time production and provides data by monitoring materials, and production.

The success of firms depends on sound warehouse plans as firms have to make the best use of available space, the best inventory counting system, the best sequence of large range of products. It will also facilitate better inventory control and efficiently coordinate the transportation of products in and out of storage. In this study each of two of the decision-making methods are applied to barcode and RFID warehouse automation systems. One of these methods is the so called AHP (Analytical Hierarchy Process), which is one of the multi-criteria decision-making (MCDM) methods used for selecting an appropriate, not necessarily perfect, and alternative. The AHP method categorizes the evaluation of experts' opinions on alternatives according to relevant criteria. FAHP (Fuzzy Analytical Hierarchy Process) is used in situations where AHP is not enough in deterministic evaluation. It is derived from traditional AHP to make decisions related to not only qualitative criteria but also quantitative criteria.

To sum up, this study comprises comparison and decision between RFID and Barcode systems. This is accomplished using AHP and FAHP methods which will be explained in detail in this report. The goal of this study is to evaluate the two mentioned warehouse data collection systems and find the best one. Firstly, AHP method is applied and FAHP is used, based on predetermined criteria.

## 2 Barcode system

A barcode is a small image of lines (bars) and spaces that is affixed to retail store items, identification cards, and postal mail to identify a particular product number, person, or location. The code uses a sequence of vertical bars and spaces to represent numbers and other symbols. The barcode keeps a reference number which indicates price and information about the product. Price and other information about the product are kept in computer. If the barcode involves price information it will be altered when the price changes which would mean an additional cost. There are many types of barcodes which involve 13 decimal places. First three numbers are country and symbol. Next four numbers represent code of the firm. Other 5 numbers are symbols of the product code and remaining one number is the control code. Different types of Barcodes are used in different areas. EAN (European Article Number), UPC (Universal Product Code), Interleaved 2 of 5 (ITF), Code 39, Code bar and Code 128 barcode alphabets are used extensively. ITF, EAN and UPC barcode alphabets just include numbers. Code 39 and Code 128 show numbers, characters and some symbols. EAN has various standards in itself. In retailer and international sales EAN 13 is utilized. Generally, Interleaved 2 of 5 (ITF) is preferred for shoe-trade and jewelry seat or applications. The numeric ITF is the most popular code used industrial applications while Code 39 is accepted to be a commercial and industrial standard by many organizations Weight, the results of measurement, location and shelves information are kept within Code 128. Code bar which is the standard code is mostly used for library and medical industry.

Reading of barcode is accomplished by the following processes. Barcode symbol is illuminated with an infrared or a distinguishable light source. Bars and spaces transfer data to the scanner. Then, scanner converts the bars and spaces to analogy voltage waves which are digitized by the decoder. Finally, this information is kept in a PC, an auxiliary or a main computer system.

The relation between messages and barcode is called symbology which means perception of spaces and bold bars in the barcode by laser reader.

### 2.1 Components of the barcode

Barcode technologies consist of 5 basic components. These are infrared rays, scanner, reader, decoder and printer.

The barcode is subjected to light in the form of infrared rays. Then, bold bars absorb the light and spaces reflect the light back to the scanner.

The light waves are converted to electrical pulses which resemble bars and spaces in barcodes by a scanner.

A barcode reader is used to read the code. The reader is sensitive to the variations in reflected laser beam due to the changes in space and bar thicknesses. The reader translates the reflected light into digital data that is transferred to a computer for immediate action or storage.

A barcode printer is a computer peripheral device for printing barcode labels or tags that can be attached to physical objects.

### 2.2 Barcode usage

Today barcode is commonly used for defining products and the error rate in a barcode system is lower than ten in a million. Information related to quality and control situation, production steps in an assembly line, stock entrance and warehouse delivery is gathered easily by barcode reader daily, weekly and monthly and is traced by computer automatically. In addition to this, barcode is used in many areas of industry such as retailing, sales, security and personnel entrance-existence trace and delivery applications.

Barcode utilization is widespread especially in warehouses as it provides speed and accuracy. User errors are eliminated by barcode usage. Collected information in the computer system is transferred to the person or environment where information will be processed. High speed data entry by computer decreases the whole system cost. In addition, tracing the products in the warehouse is provided. Especially the probability of making wrong transactions is eliminated as the cashier would not have to memorize any information about products. The collected data is reliable, fast and detailed. As a result, by considering latest sales, the products depleted in the stock are identified and the amount of replenishment to be ordered is determined easily.

Barcodes, though, can be printed on durable materials and are not affected by substrate materials or electromagnetic emissions, all of which lend them a competitive edge in some industries and environments. Improvements in how barcodes are printed are evolving all the time as manufacturers strengthen the barcode system [2].

Barcode requires line of sight to be read. It can only be read individually. It cannot be read if damaged or dirty and can only identify the type of item. It cannot be updated. It requires manual tracking and therefore is susceptible to human error [1].

## 3 RFID

RFID is based on recognition of electromagnetic proximity and data processing systems. RFID technologies use radio frequency waves to provide data transmission between a label and a reader.

RFID is a revolutionary information exchange system that can create an environment in which every object can be automatically recognized, tracked, and traced from the factory to shelf only using a single tag on each product item or pallet [3, 4, 5, 6].

For transmitting information between RFID label and reader, these two components are set to communicate in the same radio wave frequencies. All labels which are in the same RF space take the signals which are sent by the reader. Labels take emitted signals by the help of antennas installed on them and only specific label replies sending embarked data. Readers take label signals thanks to their own antennas, solve the codes and transmit data to the main computer system. Once this new technology is integrated into the infrastructure of communication networks, the data collection, service delivery and management of the system can be carried out without human intervention. Also, failure rate is decreased and speed of service and quality are increased.

### 3.1 Components of RFID

RFID technology consists of 6 basic components. These are label, antenna, reader, integrator, controller, middleware software.

A label is a device with a cover of protective layer which has an antenna and a microchip which stores information about the product. The RFID label microchip has a data storage capacity of 64 bytes to 8 MB. Labels can be passive (without battery), active (with battery) or semi-passive according to sources of energy. One of the most important details of RFID applications is choosing the correct label. The conditions of working environment, the placement of labelled product, raw materials, the reading distance of target product are directly affected by label selection.

RFID antenna is hardware which ensures communication between reader-reader and label-reader. Antennas should be designed for different scopes of size, shape and frequency to provide best performance depending on environmental characteristics and distance.

The RFID reader is a hardware which reads label information by taking signals from RFID label antenna, transmits the signal to label with its own antenna so that information can be written on the label.

The interrogator resembles a small computer which consists of 3 parts which are the antenna, the RF module and the controller. It acts like a bridge between the RFID label and controller.

The controller is a network comprising a database software application running on a computer. It is used for manipulating information and connects multiple interrogators in a network environment.

Middleware software is needed to run RFID systems. This software is developed as a product for the company in accordance with the changing company needs.

### 3.2 RFID usage

Today RFID technology has various application areas such as logistics, health, automotive, defence industries and retailer sectors. For competition purposes, retailers and manufacturers need to apply RFID, being one of the technologies in storage business providing product control, customer retention and decrease costs. Defects which occur in stocks become a threat for manufacturers and retailers. These defects are robbery, damage on products, poor placement and transaction errors. This situation causes inconsistencies between the actual and recorded amounts of the stock. RFID technology provides solutions to these problems and provides real time reliable product information. Additionally, with RFID, companies' business processes accelerate and required reports can be obtained quickly. Applying RFID makes it possible to have a perpetual inventory. This assures that retailers have access to correct information about current inventory when they need to. However, cost, data confidentiality, and standardization problems in RFID Systems limit RFID systems usage.

It has been shown that RFID tags can be adversely affected by demanding environments; for example, they are adversely affected if they are brought into contact with metal and liquids. The signal frequencies that RFID uses are also subject to interference as they are commonly used by other technologies, and RFID standards as yet have not assigned specific frequencies for RFID transmissions [4, 8, 6].

RFID can be read without line of sight. Multiple tags can be read simultaneously. It can cope with harsh or dirty environments and can identify a specific item. New information can be over-written. It can be automatically tracked removing human error [1].

## 4 AHP

AHP was one of the techniques for the MCDM developed in 1977 by Thomas L. SAATY. AHP is a mathematical method which takes into account the priorities of individuals or groups and evaluates combinations of qualitative and quantitative variables in decision-making. AHP is defined as a decision-making and prediction method that is used for defining a decision hierarchy and gives a percentage share of decision point's respect to factors which affects the decision. 'AHP is based on three principles; decomposition of a complex unstructured problem, comparative judgments about the problem components and synthesis of priorities derived from the judgments [9].

The AHP technique forms a framework of the decisions and uses a one-way hierarchical relation with respect to decision layers. The hierarchy is constructed in the middle level(s), with decision alternatives at the bottom, as shown in Fig. 1 [10].

The stages of AHP are described below:

a − Structuring the hierarchy of decision.

Firstly, the decision points are determined. Then, the factors influencing the decision are described. The number of decision points is shown with $m$ and the factors affecting the decision points are represented by $n$.

b − Establishing a comparison matrix of the factors.

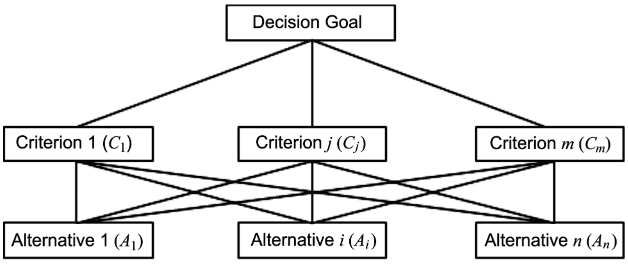


**Figure 1** Hierarchy for a typical three-level MCDM problem

The comparison matrix is a square matrix with $n \times m$ dimensions. The evaluation factors make up the rows and columns of the matrix. The comparisons are made by using the relative importance scale, as shown in Tab. 1. Since the values on the diagonal represent the same factor, they become 1. The importance value of a factor in any column is indicated by an integer. Comparative importance factor of a sector with respect to the other factors in columns is indicated by 1/importance factor.

c − Determining percentages for the importance distribution of the factors.

The ***B*** row vector with $n$×1 dimensions is established by using row vectors building the comparison matrix for importance distribution.

$$\boldsymbol{B}_i = [b_{ij}]_{n\times 1} \quad i = 1,2,...,n; \; j = 1,2,...,m. \tag{1}$$

The components of this vector are calculated by using Eq. (2), with the utilization of the elements of the comparison matrix ($a_{ij}$). In other words, the elements of the B row vector are calculated by dividing the elements in the lines of the comparison matrix with the row sums [15]. Then, the obtained $n$ times ***B*** row vector is structured in a matrix format and the median values of the elements in every row are calculated. These n values are obtained in this way and give the percentage distribution of value factors, these percentages are importance values and these values compose the priority vector ***W***. ***W*** is a priority vector with $n$×1 dimensions.

$$b_{ij} = \frac{a_{ij}}{\sum_{i=0}^{n} a_{ij}}. \tag{2}$$

d − Finding the percentages of importance distribution in $m$ decision points (alternatives) for every factor.

At this stage, the percentage of importance distribution related to every factor is determined as explained in b and c. In other words, pair-wise comparisons and matrix operations as explained in care repeated as many times as the number of factors. However, in this time the dimensions of comparison matrices to be used in decision points for every factor will become $n \times m$. After every comparison operation, S column vectors with mx1 dimensions and showing percentage distributions of every evaluated factor to the decision points are obtained [11].

e − Reaching the result distribution in the decision points

In this stage, $n$ times $S$ column vectors are all brought together. Thus, a matrix with $n \times m$ dimensions is obtained. When this matrix is multiplied with the ***W*** priority vector the percentage distribution of decision points is reached.

**Table 1** Importance scale

| Values of importance | Definitions of value |
|---|---|
| 1 | Equal Importance |
| 3 | Important |
| 5 | Very Important |
| 7 | Extremely Important |
| 2, 4, 6 | Intermediate Values |

### 4.1 Applications

Companies such as retailers and manufacturers must use their storage effectively in order to get advantage in competition. In this study, AHP is used for selecting the most appropriate system in storage among the Barcode and RFID. Four criteria are defined for making a selection between Barcode and RFID systems and which are: cost, functionality, sustainability and performance. Cost minimization is provided with a high speed data entrance to the system to increase system efficiency. Functionality lets system run faster due to being integrated with most systems. Sustainability provides adaption to competition via certain technologies. Performance refers to the increasing performance in data entrance to the system. Comparison factors are made one to one and reciprocal according to their importance. When factors are comprised the importance scale in Tab. 1 is used. Importance scales of criteria for two alternatives are given in Tab. 2.

**Table 2** Importance scale of criteria for alternatives

| Cost | Barcode | RFID | Functionality | Barcode | RFID |
|---|---|---|---|---|---|
| Barcode | 1 | 7 | Barcode | 1 | 3 |
| RFID | 1/7 | 1 | RFID | 1/3 | 1 |
| Sustainability | Barcode | RFID | Performance | Barcode | RFID |
| Barcode | 1 | 1/4 | Barcode | 1 | 1/5 |
| RFID | 4 | 1 | RFID | 5 | 1 |

Only the calculation methods for cost criterion will be presented below and calculations for the rest of the criteria can be carried out similarly.

As shown in Tab. 2, according to experts, barcode system takes 1 point where RFID system takes 7 points in terms of cost. In other words; RFID is 7 times more convenient than the barcode system in terms of cost according to experts. Subsequently, one can calculate the importance percentages of cost criterion using the scores of these two systems step by step as shown in Tab. 3, Tab. 4, and Tab. 5.

**Table 3** Calculation of importance percentages of cost criteria for two systems

| COST | Barcode | RFID |
|---|---|---|
| Barcode | 1 | 7 |
| | + | + |
| RFID | 1/7 | 1 |
| Total | =8/7 | =8 |

Importance percentages of barcode and RFID systems according to four criteria are shown in Tab. 6. Also, final solution table for the AHP is shown in Tab. 7.

The barcode system was preferred by 68 % and RFID was preferred by 32 % according to the AHP selection evaluation results given in Tab. 7.

**Table 4** Calculation of importance percentages of cost criteria for two systems

| COST | Barcode | RFID |
|---|---|---|
| Barcode | 1/(8/7)=0,875 | 7/8=0,875 |
| | + | + |
| RFID | (1/7)/(8/7)=0,125 | 1/8=0,125 |
| Total | =1 | =1 |

**Table 5** Calculation of importance percentages of cost criteria for two systems

| COST | Barcode | | RFID | Total |
|---|---|---|---|---|
| Barcode | 0,875 | + | 0,875 | 1,75/2=0,875 |
| RFID | 0,125 | + | 0,125 | 0,25/2=0,125 |
| | | | | =1 |

**Table 6** Importance percentages of four criteria

| | Cost | Performance | Sustainability | Performance |
|---|---|---|---|---|
| Barcode | 0,875 | 0,75 | 0,2 | 0,16 |
| RFID | 0,125 | 0,25 | 0,8 | 0,83 |

**Table 7** Final solution table for AHP

| System | | % |
|---|---|---|
| Barcode | 0,68 | 68 |
| RFID | 0,32 | 32 |

## 5 FAHP

In the decision-making process, there was unquantifiable, incomplete, unobtainable information and partial ignorance. For this reason we used FAHP method for analysing our decision model as a Fuzzy multi-criteria decision-making method (FMCDM). Namely we combined AHP method with fuzzy set theory as a FMCDM method.

FMCDM methods have been developed due to the imprecision in assessing the relative importance of attributes and the performance ratings of alternatives with respect to attributes. Imprecision may arise from a variety of reasons: unquantifiable information, incomplete information, unobtainable information and partial ignorance. Conventional MCDM methods cannot effectively handle problems with such imprecise information. To resolve this difficulty, fuzzy set theory, first introduced by Zadeh (1965), has been popularly used [12]. Additionally in many cases, the preference model of the human decision maker is uncertain, and it is relatively difficult for the decision maker to provide exact numerical values for the comparison ratios [12].

Basic decision-making problems can be structured hierarchically. But selection of warehouse data collection system is a decision problem which cannot be structured hierarchically like many other decision problems, because it involves the interaction and dependence of higher-level elements in a hierarchy on lower level elements. This is another reason why FAHP was selected as a methodology for this study.

FAHP is a problem-solving technique which is a combination of AHP process use of fuzzy logic and linguistic variables.

Chang's fuzzy extent (dimension) analysis method is considered for FAHP [13]. In this method, $X$ is a destination set $X=\{x_1, x_2, x_3, \dots, x_n\}$ and $U$ is an objective set $U=\{u_1, u_2, u_3, \dots, u_n\}$. To apply the process depending on this hierarchy, according to the method of Chang's (1992) extent analysis, each criterion is taken and extent analysis for each criterion $g_i$ is performed on, respectively. Therefore, m extent analysis values for each criterion can be obtained by using the following notation: [13]

$$M_{g_i}^1, M_{g_i}^2, M_{g_i}^3, M_{g_i}^4, M_{g_i}^5, \dots, M_{g_i}^m, \tag{3}$$

where $g_i$ is the goal set $i=\{1, 2, 3, 4, 5, \dots, n\}$ and all the $M_{g_i}^j$ $j=\{1, 2, 3, 4, 5, \dots, m\}$ are Triangular Fuzzy Numbers (TFNs). The steps of Chang's analysis can be given as in the following:

**Step 1:** The fuzzy synthetic extent value $S_i$ with respect to the $i^{th}$ criterion is defined as Eq. (4).

$$S_i = \sum_{j=1}^{m} M_{g_i}^j \otimes \left[ \sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^j \right]^{-1}. \tag{4}$$

To obtain Eq. (4), $\sum_{j=1}^{m} M_{g_i}^j$ perform the "fuzzy addition operation" of $m$ extent analysis values for a particular matrix given in Eq. (5) below, at the end step of calculation, new ($l$, $m$, $u$) set is obtained and used for the next:

$$\sum_{j=1}^{m} M_{g_i}^j = \left( \sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j \right), \tag{5}$$

where $l$ the lower is limit value, $m$ is the most promising value and $u$ is the upper limit value. And to obtain Eq. (6)

$$\left[ \sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^j \right]^{-1}, \tag{6}$$

perform the "fuzzy addition operation" of $M_{g_i}^j$ $j=\{1, 2, 3, 4, 5, \dots, m\}$ values give as Eq. (7):

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^j = \left( \sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i \right). \tag{7}$$

And then compute the inverse of the vector in the Eq. (6) and Eq. (7) is then obtained such that

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^j = \left( \sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i \right) \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}. \tag{8}$$

**Step 2:** The degree of possibility of $M_2 = (l_2, m_2, u_2) \geq M_2 = (l_1, m_1, u_1)$ is defined as Eq. (9):

$$V(M_2 \geq M_1) = \sup_{y \geq x}[\min(\mu_{M_1}(x), \mu_{M_2}(y))] \cdot \quad (9)$$

And $x$ and $y$ are the values on the axis of membership function of each criterion. This expression can be equivalently written as given in Eq. (10) below:

$$V(M_2 \geq M_1) = \begin{cases} 1 & \text{if } m_2 \geq m_1 \\ 0 & \text{if } l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & \text{otherwise} \end{cases} \cdot \quad (10)$$

Where d is the highest intersection point $\mu_{M_1}$ and $\mu_{M_2}$ [14]. To compare $M_1$ and $M_2$ we need both the values of $V(M_2 \geq M_1)$ and $V(M_1 \geq M_2)$.

**Step 3:** The degree possibility for a convex fuzzy number to be greater than $k$ convex fuzzy numbers $M_i$ ($i$ = 1, 2, 3, 4, 5,..., $k$) can be defined by the Eq. (11):

$$V(M \geq M_1, M_2, M_3, M_4, M_5, M_6, ..., M_k). \quad (11)$$

One can say from the Eq. (11) $V[(M \geq M_1)$ and $(M \geq M_2)$ and $(M \geq M_3)$ and $(M \geq M_4)\ldots(M \geq M_k)]$ The Eq. (11) is equal to min $V(M \geq M_i)$, $i$ = 1, 2, 3, 4, 5, ..., $k$.

Assume that Eq. (12) is

$$d^1(A_i) = \min V(S_i \geq S_k). \quad (12)$$

For $k$ = 1, 2, 3, 4, 5,..., $n$; $k \neq i$. Then the weight vector is given by Eq. (13):

$$W^1=(d^1(A_1), d^1(A_2), d^1(A_3), d^1(A_4), d^1(A_5),..., d^1(A_n))\text{^T}, \quad (13)$$

where $A_i$ ($i$ = 1, 2, 3, 4, 5, 6,…, $n$) are $n$ elements.

**Step 4:** Via normalization, the normalized weight vectors are given in Eq. (14):

$$W=(d(A_1), d(A_2), d(A_3), d(A_4), d(A_5),..., d(A_n))\text{^T}, \quad (14)$$

where $W$ is non-fuzzy numbers.

After the criteria have been determined, a question form has been prepared to determine the importance levels of these criteria. To evaluate the questions, people only select the related linguistic variable, then for calculations they are converted into the following scale including TFN developed by Chang, 1996 and generalized for such analysis as given in Tab. 8 below [15]. Also, final solution table for the AHP is shown in Tab. 9.

**Table 8** TFN values

| Statement | TFN |
|---|---|
| Absolute | (7/2,4,9/2) |
| Very Strong | (5/2,3,7/2) |
| Fairly Strong | (3/2,2,5/2) |
| Weak | (2/3,1,3/2) |
| Equal | (1,1,1) |

The results of selection evaluation implemented by FAHP are similar to AHP shown in Tab. 9. According to these results, barcode system was preferred by 72 % and RFID was preferred by 28 %.

**Table 9** Final solution values for FAHP

| System | | % |
|---|---|---|
| Barcode | 0,72 | 72 |
| RFID | 0,28 | 28 |

## 6 Conclusion

In recent years warehouse automation has earned meaning with developing technologies in the supply chain. Companies have begun to use effectively their storage to become leaders in a competitive environment. Companies prefer Barcode and RFID systems for warehouse automation. Some of the subjective criteria which are used in decision-making problem to find a solution by using MCDM method make this process quite easy. MCDM methods based on linguistic evaluations like AHP help to make a better selection decision by using a weighting process within the current alternatives via pairwise comparisons.

In this study AHP and FAHP are used for making a choice between the Barcode and RFID systems. 4 criteria affect the selection decision, and these are: cost, functionality, sustainability and performance. These criteria's relative importance values are shown in Tab. 10.

**Table 10** Relative importance of four criteria

| | Cost | Functionality | Sustainability | Performance |
|---|---|---|---|---|
| Cost | (1,1,1) | (1,3,5) | (5,7,9) | (3,5,7) |
| Functionality | (1/5,1/3,1) | (1,1,1) | (3,5,7) | (1,3,5) |
| Sustainability | (1/9,1/7,1/5) | (1/7,1/5,1/3) | (1,1,1) | (1/5,1/3,1) |
| Performance | (1/7,1/5,1/3) | (1/5,1/3,1) | (1,3,5) | (1,1,1) |

According to AHP results, it is seen that barcode was preferred by 68 % and RFID was preferred by 32 %. In FAHP result of comparison it is seen that Barcode was preferred by 72 % and RFID was preferred by 28 %. Also in Chang's method, sustainability criteria was zero. For this reason, it does not affect results. Importance levels of four criteria are shown in Tab. 11.

**Table 11** Importance scale

| Importance level of criteria | |
|---|---|
| Cost | 0,47 |
| Functionality | 0,36 |
| Sustainability | 0 |
| Performance | 0,16 |

By using these methods, evaluation of two systems resulted in the conclusion that Barcode was selected as the appropriate system for the company's warehouse, as AHP is not suitable for decision-making processes comprising uncertainty. For this reason, fuzzy logic is combined with AHP, and FAHP is applied. As a result AHP values are consistent with FAHP values.

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